The Evaluation of 3-Dimensional Polymerization Changes of a Denture Resin Utilizing Injection Molding with Water Bath Polymerization and Microwave Polymerization

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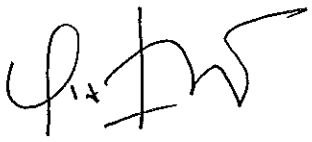

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ABSTRACT

Objectives:

To compare the effect of microwave polymerization and conventional water bath polymerization on the three dimensional polymerization changes of Lucitone 199®, a poly methyl methacrylate denture resin.

Materials and Methods:

The study used a randomized observational design. Thirty SLA master dies, in the form of a maxillary denture base, were fabricated to include a sequence number (1-30) and a set of fiducial markers. The distance of the fiducial markings were recorded for each SLA master die using a contact scanning device (FARO Gage arm). The SLA master dies were randomly assigned to one of two testing groups and sequencing numbers for each group were recorded in a log (see 6.3.4). From the SLA master dies, 30 acrylic resin denture bases were fabricated. Half were polymerized by water bath and half by microwave. Following polymerization by the manufacturer's instructions, all resin denture bases were retrieved from the denture flasks. The PI removed each resin denture base from the water, conducted a three-dimensional evaluation utilizing the FARO Gage arm and several fiducial markers against each record base's own SLA master die to determine three-dimensional polymerization changes. The data was analyzed by a multivariate analysis of variance (MANOVA).

Results:

MANOVA revealed no difference in the mean vectors simultaneously between the two groups. Differences in the mean vectors of the coordinate axes between polymerization

methods were also noted.

Conclusions:

The objective of this study is to determine if there are any differences between microwave polymerization method and water-base polymerization method with respect to 3-dimensional linear distances, in microns, from a centroid measured at nine different fiducial points on a processed acrylic. Microwave polymerization shows statistically less 3 dimensional changes compared to conventional water bath polymerization however clinically both material present almost identical results.

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LIST OF ABBREVIATIONS

SLA	……	Stereolithography
PI	……	Primary Investigator
PMMA	……	Poly Methyl Methacrylate
ADA	……	American Dental Association
ANOVA	……	Analysis of Variance
MANOVA	……	Multivariate Analysis of Variance
WBP	……	Water Bath Polymerization
MWP	…….	Microwave Polymerization
WRNMMC	…….	Walter Reed National Military Medical Center

INTRODUCTION

The objective of this study was to compare the effect of microwave polymerization and conventional water bath polymerization on the three dimensional polymerization changes of Lucitone 199®, a poly (methyl methacrylate) denture resin.

Hypothesis: The three dimensional polymerization changes of Lucitone 199® resin denture bases polymerized by microwave radiation will not differ from the three-dimensional polymerization changes of Lucitone 199® resin denture bases polymerized by conventional water bath.

Lucitone 199® is a poly(methyl methacrylate) denture resin that is typically polymerized using a water bath at 163°F ± 2°F for 8 or 9 hours. However, according to the manufacturer, Lucitone 199® can be polymerized utilizing microwave radiation in 15 minutes. This study should provide data that shows whether or not microwave polymerization of denture resin, in 1/36 of the time for traditional water bath polymerization, produces minimal three-dimensional polymerization changes, and therefore will not compromise denture base adaptation, stability, retention, and function. If polymerization by microwave radiation is as effective as by water bath, vast amounts of laboratory time could be saved and much quicker delivery of dentures and acrylic orthotic devices to military members could be achieved.

REVIEW OF THE LITERATURE

The literature search concerning microwave polymerization of acrylic resin using the PubMed and Google Scholar databases was initially conducted on June 3, 2010 and revisited in March 2015.

Dentures are removable prostheses that replace lost jaw structure and missing teeth. They require many steps to fabricate. Initially, impressions of the upper and lower jaws are made and then poured with stone to make models called casts. Using wax templates, the skeletal relationship of the upper and lower jaw (how the jaws relate to each other in space) is recorded. These wax templates are used to mount the casts on a device called an articulator which duplicates the spatial relationship of the patient's jaws. Once articulated, wax dentures are produced to restore the missing teeth and jaw tissues. The cast with the wax denture is then separated from the articulator, placed in the center of a specialized container or flask, and dental stone is poured to fill up the flask and surround the wax denture. When the stone has hardened, the flask is placed in boiling water to eliminate the wax and create the mold into which denture acrylic resin is introduced once the flask has cooled.

In 2015, denture fabrication still uses acrylic denture resin consisting of poly(methyl methacrylate) (PMMA) that was introduced to dentistry in 1937 by Dr. Walter Wright.[1] This resin is a resilient plastic that is supplied as a powder-liquid system, as defined and directed by American Dental Association (ADA) specification 12.[2, 3] The powder, commonly known as the polymer, consists of particles of pre-polymerized PMMA and a small amount of benzoyl peroxide. The benzoyl peroxide is responsible for starting the polymerization process and is called the *initiator*.[4] The liquid, commonly known as the

monomer, is mainly non-polymerized methyl methacrylate with small amounts of other components that aid polymerization of the resin.[4] When the powder and liquid are combined the *initiator* prompts methyl methacrylate molecules or "mers" to join the powder particles and form chains or "polymers." (see Figure 1.).[4]

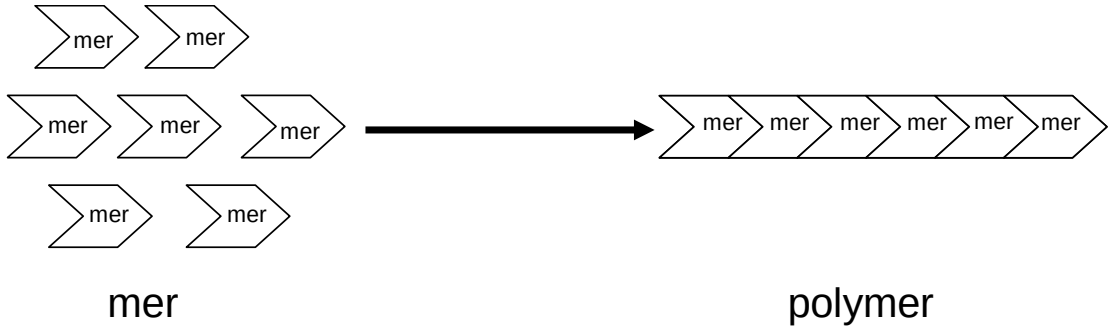

Figure 1. Polymerization process – each "mer" is linked in a chain-like fashion forming a "polymer."

The polymerization process consists of five distinct phases characterized by changing physical properties (sandy, stringy, dough-like, rubbery or elastic, and stiff). When the powder and monomer for heat cured denture resins are mixed at room temperature the *initiator* gets the polymerization process to the dough-like phase in about 8 to 9 minutes. To achieve thorough polymerization to a hard "polymerized" resin that exhibits minimal porosity and maximum strength requires controlled application of external heat.[4] The heat application is referred to as the *activator,* and can be achieved via water bath or microwave-produced thermal energy.[4] The heat *activator* is needed because the *initiator* benzoyl peroxide must be heated above 140°F to form a reactive molecule (a free radical) that can efficiently react with available monomer molecules to promote widespread, even polymerization.[4] (see Figure 2.)

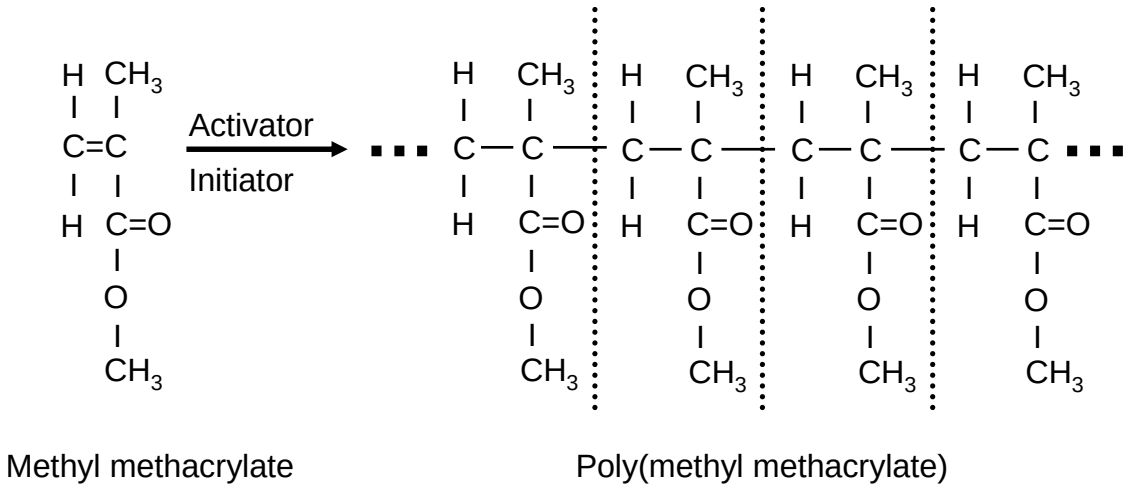

Figure 2. Individual methyl methacrylate molecules or "mers," with the proper conditions, will join in repeating units to form a polymer chain. The resulting compound is *poly(methyl methacrylate)*. [5]

Although external heat is necessary to fully activate denture resin polymerization, once started, the polymerization generates heat (exothermic), and the rate of heat production is proportional to the rate of polymerization.[4] To produce the most beneficial physical properties in a denture, both the rate of polymerization and the amount of heat generated must be controlled. If too much heat is applied, the polymerization rate proceeds too quickly, and the excessive heat causes un-reacted liquid monomer within the resin mass to boil away before it can combine with the particles. This is how excessive heat creates porosity within the resin and results in high internal stress, and vulnerability to distortion and warpage. Also, if the denture base is cooled too rapidly following the polymerization cycle, the acrylic may warp secondary to the differences in thermal contraction of the acrylic resin and investment material.[4,9]

Dentures replace lost teeth, bone, and soft tissue, and in doing so, phonetic speech, function for mastication, and esthetics are restored. Prosthetic success achieved through complete

denture therapy involves many factors. Patient acceptance of the final prostheses depends on biological, physical and mechanical factors that are determined or affected by the properties of retention, stability and support of the complete dentures. Intimate adaptation of the intaglio surface, or tissue bearing surface, of the denture base to the soft tissues covering the edentulous maxilla or mandible is significant in maintaining proper retention and stability of the complete denture, both during rest and function. [5] Several effects from the polymerization process of heat activated acrylic resins, including distortion, linear shrinkage, and volumetric shrinkage, can cause changes in the adaptation of the denture base to the tissues. This in turn, adversely affects retention, stability, intercuspal interdigitation (occlusion), and tissue health, all compromising clinical performance. [6]

According to Phillips' Science of Dental Materials, volumetric shrinkage and linear shrinkage demonstrated by heat activated acrylic resins are 6-7% and 0.2–0.5%, respectively. Many advances have been made in acrylic resin materials and the processing techniques used. However, no combination of materials or techniques have been able to produce heat-processed acrylic resin shrinkage values less than those listed above. [7]

According to ADA Specification 12 regarding working qualities of cured resins: "The polymer, when processed according to the instructions furnished by the manufacturer (3.4.3), shall yield a satisfactory denture."[2, 3] Additionally, because PMMA dentures undergo inherent expansion and contraction changes due to heating and cooling during polymerization and processing that may distort the final denture, every effort to reduce dimensional change and porosity should be exercised.[15-6]

The aforementioned considerations have guided evolution of the following paradigm for producing heat-cured resin dentures with minimal dimensional change. Once the flask has cooled following wax denture elimination and the PMMA powder and liquid mixture reaches the dough-like stage, it is placed into the mold which is surrounded by dental stone in the flask. The flask is immersed in a water bath maintained at 163±2°F for 8 to 9 hours to complete polymerization. This temperature and time duration allows uniform polymerization of denture resin with the least degree of distortion and linear and volumetric changes. After polymerization, the denture is removed from the flask and prepared for delivery to the patient.[4]

Since 1937, advances in PMMA technology such as injection molding of denture resin rather than compression molding and development of polymers with improved physical properties have been achieved.[17-22] Another technique, microwave activation of PMMA aimed at shortening the 8 to 9 hours necessary for polymerization via the water bath, was introduced to dentistry in 1968 by Nishii.[20] After more than three decades of work,[24] the benefits afforded by microwave activation include greatly reduced polymerization time,[25] cleaner denture processing,[26] and denture bases that possess superior adaptation to the dental cast.[27] In addition, compared to the conventional water bath, the use of microwave energy to cure denture resin may result in better denture base adaptation to denture bearing tissues intraorally.[10]

In 1999, Dentsply International (York, PA) introduced the Success injection system that utilized a conventional, water bath-cured PMMA (Lucitone 199®).[29] During the same

year, Dentsply revealed a microwave denture processing technique that employs a specialized composite flask that is safe for microwave use.[31] However, their microwave system utilizes the Success system and Lucitone 199® that was originally designed for polymerization by the water bath. To date, no research has been published that evaluates the use of Lucitone 199® with this microwaveable system. This proposal has been designed to evaluate the three-dimensional changes of acrylic resin denture base samples of Lucitone 199® that are polymerized according to Dentsply International's directions for polymerization by water bath and microwave radiation.

MATERIALS AND METHODS

The study is a bench top, observational laboratory study that used a randomized observational design. Thirty SLA master dies, in the form of a maxillary denture base, were fabricated to include a sequence number (1-30) and a set of fiducial markers. The distance of the fiducial markings were recorded for each SLA master die using a contact scanning device (FARO Gage arm). The master SLA master dies were placed in a box from which the primary investigator withdrew at random a single SLA denture base and assign it to one of two testing groups until all SLA denture bases were assigned. The sequencing numbers for each group were recorded in a log (see 6.3.4). From the SLA master dies, 30 acrylic resin denture bases were fabricated by the primary investigator. Half were polymerized by water bath and half by microwave. Following polymerization by the manufacturer's instructions, the primary investigator retrieved all resin denture bases from the denture flasks. The PI removed each resin denture base from the water, conducted a three-dimensional evaluation utilizing the FARO Gage arm and several fiducial markers against each record base's own

SLA master die to determine three-dimensional polymerization changes. Data was analyzed by two-way analysis of variance (ANOVA).

Study Methodology/Procedures

Three week testing period

At the beginning of each week for 3 weeks, 10 acrylic resin denture bases of Lucitone 199® were fabricated; half were polymerized by water bath and half by microwave. This schedule was developed due to the time involved in manufacturing denture bases before three-dimensional assessments with the FARO Gage arm (Figure 3). Over a three-week testing period, 30 Lucitone 199® resin denture bases were made using the Success Injection system®.

Dimensions of denture bases

30 denture bases were fabricated with a uniform thickness of 2-3 mm. For each denture base, 15 were polymerized by water bath and 15 by microwave radiation. The 2-3 mm measure was chosen because it is a common dimension of a denture base.[13]

Sequence to produce master standardized resin denture bases (SLA master dies)

Preliminary Lab Work

Utilizing computer software (Rhino), a denture record base standard was designed and simulated to include a set of fiducial markers, and a sprue form specific for the Success Injection system®.

- The sprue technique defined by Dentsply International for their Success Injection system® was used.[29]
- A sprue is the channel or hole through which plastic or metal is poured or cast into a mold.[30]
- Each standard had a sequence number that translated to the processed specimen.

o From this simulated denture record base, 30 standardized individual SLA denture bases were fabricated utilizing a photo initiated resin (Accura 60).(Figure 3)

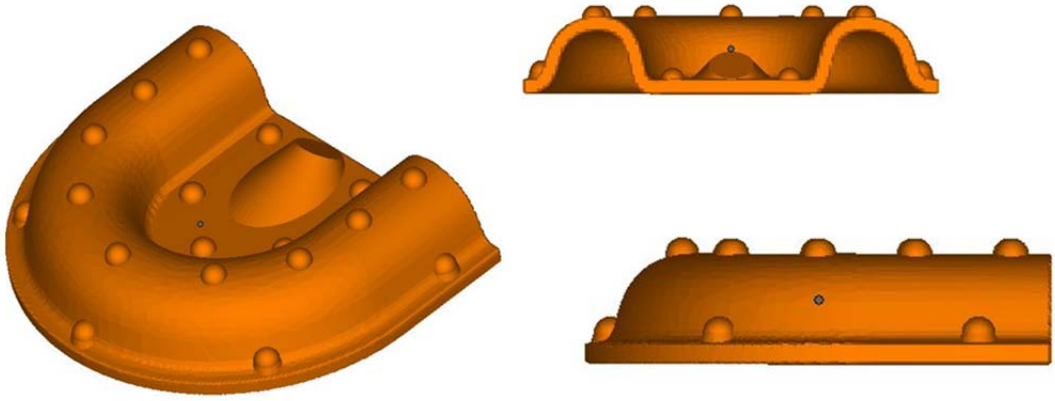

Figure 3. CAD design of the denture bases for SLA fabrication

- The 30 SLA master dies served as master dies (see Figure 3)
- Each of the 30 SLA master dies were evaluated individually in three dimensions, utilizing the FARO arm and set the mechanical center for each of the fiducial markers; the results were documented (6.3.4), and served as the baseline measurements for each of the 30 respective processed resin denture base samples.

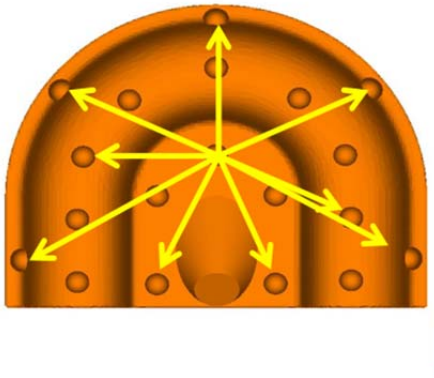

Figure 4: vector measurement from the origin to 9 fiducial markers.

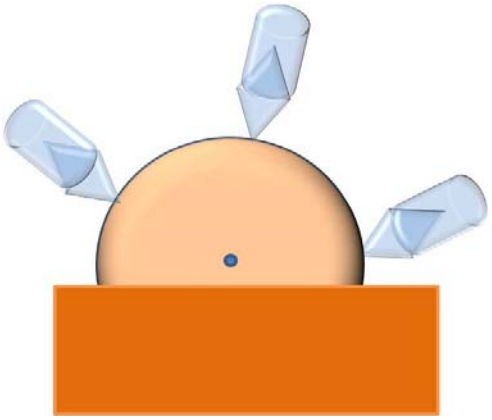

Figure 5: point probe positions to find the mechanical center of the spheres

- Direction of the measurement was from a point of origin to 9 fiducial markers on the denture base. (see Figure 4.)
- Each fiducial marker was measured using the contact scanner (Gain FARO arm) with a point scanner point for 5 different locations to locate the mechanical center of the fiducial marker. (See Figure 5.)
- From a box the PI withdrew SLA denture bases and divided them into the two processing groups.

<u>Benchmark Measurements of the SLA Master Dies</u>

The centroid of each fiducial marker was accurately located using a FARO Gage Series contact probe coordinate measurement device (FARO Arm). The FARO Arm (see Figures 6&7.) is a precise

Figure 6. FARO Arm

coordinate measurement device with National Institute of Standards and Technology (NIST) traceable calibration and resolution on the order of 10 microns; thus, it was a suitable device to obtain benchmark locations of the fiducial markers in 3-D space.

The SLA master dies were mounted to a stable workbench using a hot glue gun providing access to the fiducial markers. The position of each surface fiducial marker was measured. Five or more evenly distributed points were sampled on the surface of each spherical fiducial marker by positioning the tip of the FARO Arm at the desired location and recording the sampled position in space. All measurements were referenced to the same fixed reference coordinate system at the base of the FARO Arm. The 3-D position of each sphere's centroid were automatically calculated from the set of points using the "Features and Datums" module in the FARO 13.0 software. The measurement process is visualized in Figure 7. A minimum of nine independent sets of measurements on the base plate SLA master die were recorded as the dimensional benchmark.

The locations of all ten surface fiducial markers were mathematically transformed from the original reference coordinate system to a new coordinate system with its origin at the centroid of the mid palatal marker.

Production of resin denture bases by the PI

- SLA master dies were processed first to make resin denture bases for water bath polymerization, the much longer process.
- Metallic flasks were used for the water polymerization while composite flasks are used for microwave polymerization.

- Other than the flask's composition and method of polymerization there were no differences in manufacturing technique to make resin denture bases.

For water bath:

- Each SLA master die was invested with dental stone within a *metallic* flask and placed in the boil-out tank for five minutes to heat the flasks in order to simulate the actual laboratory procedure for denture fabrication.
- After five minutes, the flasks were removed from the boil-out tank, allowed to cool, opened and the SLA master dies will be removed from the flasks and set aside.
- The investment stone was coated with a tin-foil substitute (per manufacturer's recommendations) to prevent adhesion of the denture acrylic to the dental stone.
- The flasks were reassembled.
- According to the manufacturer's instructions the Lucitone 199® denture acrylic will be mixed and injected by the Success® machine through the sprue space into each mold.
- The flasks were polymerized by water bath set at 163°F ± 2°C F for 9 hours.

For microwave:

- Each SLA master die was invested with dental stone within a *composite* flask and placed in the boil-out tank for five minutes to heat the flasks in order to simulate the actual laboratory procedure for denture fabrication.
- After five minutes, the flasks were removed from the boil-out tank, allowed to cool, opened and the SLA master dies were removed from the flasks and set aside.

- The investment stone was then coated with a tin-foil substitute (per manufacturer's recommendations) to prevent adhesion of the denture acrylic to the dental stone.
- The flasks were reassembled.
- According to the manufacturer's instructions the Lucitone 199® denture acrylic was mixed and injected by the Success® machine through the sprue space into each mold.
- The flasks were then polymerized in the calibrated (according to the manufacturer's instructions) microwave oven for 15 minutes.
- After polymerization the PI opened each flask, removed the resin denture bases, and by rotary disc sectioned each of the resin denture bases from the sprue.

<u>Resin denture base measurements by PI</u>

Three-Dimensional testing

- Each numbered processed denture base was subjected to the same three-dimensional evaluations, utilizing the FARO arm and said fiducial markers, as the respective original SLA master die.

Figure. 7 measurements

- Positions of the fiducial markers, as reproduced on the processed denture bases, were measured with the FARO Arm following the same procedure described for measuring the fiducial markers on the SLA master dies. The processed base plates were mounted on the FARO Arm table in the same manner. A minimum of five independent sets of measurements were sampled and recorded for each processed denture base. The room temperature and elapsed time since model fabrication was recorded along with the measurement data.

- Results will be recorded on the data collection sheet next to the resin denture base number.

Data Collection

Each of the original SLA master dies was assigned a sequence number 1-30. Initial three-dimensional measurements of the master SLA master dies were made with the FARO arm and recorded.

As the 30 subsequent acrylic resin denture bases were fabricated and tested for three-dimensional polymerization changes, values were recorded in the Data Collection Sheet according to the assigned number for each denture base.

Positions of the fiducial markers, as reproduced on the processed denture base, were measured with the FARO Arm following the same procedure described for measuring the fiducial markers on the SLA master die. The processed denture bases were mounted in the same manner. A minimum of five independent sets of measurements were sampled and recorded for each processed denture base. The room temperature and elapsed time since model fabrication were recorded along with the measurement data.

After all data for the 30 denture bases were recorded on the data sheets, the data was organized by denture bases polymerized by water bath or microwave and were analyzed by multivariate analysis of variance (MANOVA).

Study Time Line

	Week 1	**Week 2**	**Week 3**	**Week 4**
Day 1	Sample Fabrication	Sample Fabrication	Sample Fabrication	Break Code and Data Analysis
Day 2	Sample Storage	Sample Storage	Sample Storage	
Day 3				
Day 4	FARO analysis	FARO analysis	FARO Analysis	

Statistical Considerations

Dr. Tuamokumo, the WRNMMC statistician in Darnell Library, was consulted for statistical design.

The primary endpoints (i.e., primary outcome variables) and the secondary endpoints, if any.

Primary outcome variables: the three-dimensional changes for each resin denture base.

Data analysis

All measurements from each processed denture base sample were translated and rotated into the coordinate system (basis) of the original SLA master die; the coordinate transformation was computed in Microsoft Excel. Details of the coordinate transformation are provided in the Appendix A.

After all data for the 30 resin denture bases were collected, the Resin Denture Base Log was provided by the AI to reveal which numbered denture base belongs to which group: WBP for water bath polymerization, and MWP for microwave polymerization. Then data from the data collection sheet was imported into EXCEL to perform the multivariate analysis of variance (MANOVA) to determine the relationship between polymerization method and dimensional changes in the denture base.

Sample Size Estimation

The objective of the study was to determine the effect of polymerization (heat, microwave) on the three-dimensional changes of the material. Sample size calculations were based on the three-dimensional changes that occur with either polymerization method. A review of the literature indicated that the mean volumetric shrinkage and mean linear shrinkage, under heat polymerization technique, is 6-7% and 0.2-0.5%, respectively.[21] It was anticipated that the three-dimensional changes, using the microwave technique would produce a mean modulus value of about 2.18%, assuming the same amount of variability. Thus, controlling for a type I error of .05 and a power of 80%, a sample size of 15 per group for a total of 30 samples was needed for the two by two factorial analysis.

RESULTS

The objective of this study was to determine if there are any differences between microwave polymerization method and water-base polymerization method with respect to 3-dimensional linear distances, in microns, from a centroid measured at nine different fiducial points on a processed acrylic. The SLA denture base was used as a control. Because of this pre-post construct, the analysis involved calculating the absolute value of pre-post differences on all the coordinate axes. The multivariate analysis of variance (MANOVA) was performed on the data to test the hypothesis of no difference in the mean vectors simultaneously between the two groups. The experimental runs were randomized into the two groups.

With Hoteling's T-square as the test statistic, the p-value was found to be less than .0001, suggesting that there are differences in the mean vectors of the coordinate axes between the polymerization methods. Both assumptions of multivariate normality and the equality of the variance-covariance matrices were satisfied. Bartlett's test of sphericity of the residual covariance matrix was satisfied (that is, not equal to an identity matrix)

Descriptive Statistics

	Group	Mean	Std. Deviation
X	WaterBase	31.90	15.01
	Microwave	11.11	17.87
Y	WaterBase	27.05	16.75
	Microwave	8.57	14.20
Z	WaterBase	0.46	0.50
	Microwave	0.60	1.61

DISCUSSION

Our evidence suggests that there was a statistical difference between standardized record bases processed with conventional water bath polymerization and microwave polymerization. The difference, although significant statistically was only on 2 of the 3 axis or coordinates evaluated (X and Y). The X axis represented the transversal axis of the record base which it is well documented in the prosthodontic literature to be the area where linear shrinkage may be expected. The Y axis represents the anterior-posterior axis of the bases and the Z axis represents a vertical axis of the base.

This study provides data that shows that microwave polymerization of denture resin, in 1/36 of the time for traditional water bath polymerization, produces minimal three-dimensional polymerization changes, and therefore will not compromise denture base adaptation, stability, retention, and function. It also demonstrates that polymerization by microwave radiation is as effective as by water bath and by using this methodology. Vast amounts of laboratory time can be saved and much quicker delivery of dentures and acrylic orthotic devices to military members and patients in general can be achieved.

Future studies are needed to investigate if the results of this study would apply when varying the thickness of the denture base resin.

CONCLUSIONS

Our evidence suggests that Microwave polymerization shows statistically less 3 dimensional changes compared to conventional water bath polymerization. However from a clinical perspective both materials present almost identical results. The other major advantage of the microwave polymerization technique is the speed of processing compared to conventional heat activated polymerization.

APPENDIX A

SPECIMEN COLLECTION DATA SHEET

Sequence number	*Polymerization method*	*Fiducial point*	*SLA denture base*			*Processed Acrylic denture base*		
(1-30)	*WBP/MWP*		*X*	*Y*	*Z*	*X*	*Y*	*Z*
		1						
		2						
		3						
		4						
		5						
		6						
		7						
		8						
		9						
		10						
		1						
		2						
		3						
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